REVIEW ARTICLE

Cataract Surgery With Implantation of an Artificial Lens

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SUMMARY

Background: Cataract surgery, the most frequently performed operative procedure worldwide, typically concludes with the implantation of an artificial intraocular lens (IOL) to correct aphakia (absence of the crystalline lens).

Method: Selective literature review including current regulations, guidelines and recommendations for cataract surgery.

Results: The main symptom of cataract is loss of visual acuity, which usually progresses slowly. It can arise in one eye or both. There is a basic distinction between congenital and acquired cataracts. The probability of developing a cataract rises with age because of biochemical aging processes. The development of a cataract becomes highly likely from the sixth decade of life onward.

Conclusions: As no effective medications for cataract are available at present, its current standard treatment is the removal of the clouded lens. In industrialized countries, this is usually done with ultrasound (phacoemulsification), followed by the implantation of an IOL.

Key words: cataract, ophthalmic surgery, artificial lens, minimally invasive treatment, visual acuity

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Opacification of the natural lens of the eye (cataract) is the most common cause of blindness around the world (1). In Germany alone, more than 600 000 cataract operations are performed annually, according to industry data, and the corresponding figure worldwide is estimated at between 6 and 10 million. The number of cataract operations per 1 million people per year (the cataract surgery rate, or CSR) varies highly from one country to another: according to the World Health Organization, the CSR is 4000 to 5000 in the United States and in Europe, but only about 3000 in semi-industrialized countries such as India, and as low as 200 in some Third World countries (1).

The most common type of cataract is the age-related (senile) cataract, which appears from the sixth decade onward (e1, e2). As there is no pharmacological treatment for cataract, the standard treatment is surgical removal of the opacified lens and implantation of an artificial intraocular lens (IOL) (e2). Minimally invasive surgical technique is very important for the prevention of complications such as surgically induced astigmatism or intraocular infection, which is usually bacterial ("endophthalmitis") (2, e3, e4). Modern IOL optics enable a high quality of vision after surgery, and thus patient satisfaction is high (3–5, e5, e6). This article provides an overview of the clinical manifestations of cataract, of the established and innovative methods of treatment, and of the necessary follow-up care. The benefit of IOL implantation is discussed with regard to the visual results as well as to potential complications and the frequency with which they occur.

Cataracts

Types of cataract

As cataracts have many different causes and varieties, they can be classified in many different ways *(Box)*. One basic distinction is that between congenital and acquired (e.g., senile, traumatic, or glaucoma-related) cataracts (e2).

Congenital cataract is defined as opacification of the lens that is already present at birth or arises during the first year of life (e7). Its causes include intrauterine infections, metabolic disorders, and a wide variety of congenital syndromes. The intrauterine infectious diseases that most commonly cause congenital cataracts are rubella, measles, herpes simplex, varicella,

BOX

Some common causes of congenital and acquired cataracts (e2)

Congenital
- Intraoperative infections (rubella, measles, herpes simplex, varicella, Epstein-Barr virus, influenza, syphilis, toxoplasmosis)
- Genetic causes (familial congenital cataract, galactosemia, trisomy 21, trisomy 13, Lowe syndrome)

Acquired
- Aging
- Toxic effect (e.g., smoking, medications)
- Radiation (ultraviolet light)
- Systemic diseases (e.g., diabetes, atopic dermatitis, hypocalcemia)
- Ocular diseases (uveitis, infections, glaucoma)
- Trauma

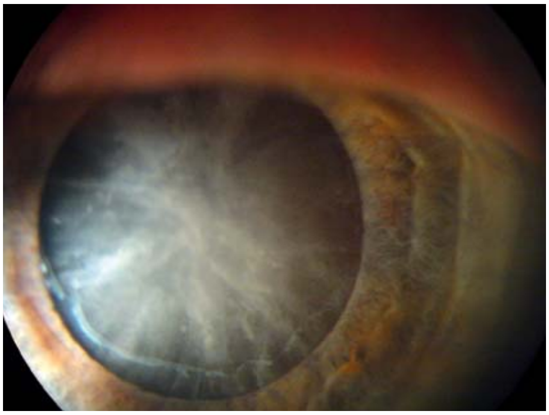

Figure 1: Age-related (senile) cataract

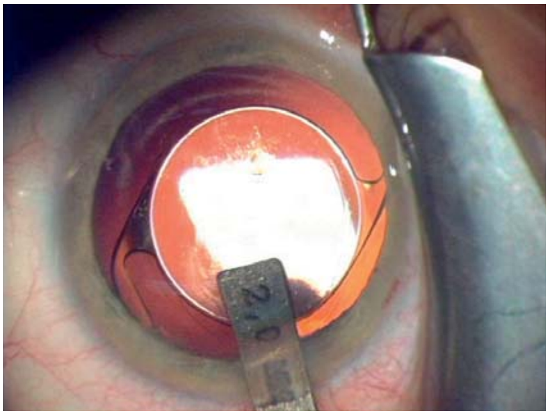

Figure 2: Measurement of incision size (2.0 mm) after phacoemulsification and microincisional implantation of a one-piece, aspherical acrylate intraocular lens (e17)

Epstein-Barr virus, influenza, syphilis, and toxoplasmosis. Common genetic causes include, for example, familial congenital cataract, galactosemia, trisomy 21, trisomy 13, and Lowe syndrome (e8). The opacified lens can take on many different appearances, depending on the particular part of it that is affected.

The most common type of cataract, however, is the senile cataract, which has three main varieties: peripheral, nuclear, and posterior subcapsular opacification (e2). Different types of lenticular opacification impair vision in different ways: for example, central nuclear opacification lowers acuity, but posterior subcapsular opacification makes the patient very sensitive to glare (e9).

Clinical manifestations of cataract

The main manifestation of cataract is a worsening of vision, which is usually slowly progressive. The impairment is not limited to high-contrast visual acuity; it also extends to other aspects of vision, such as glare disability (e9, e12).

Opacification of the nucleus of the lens can also manifest itself as an increase in the refractive power of the lens, so that the refractive power of the eye changes in the direction of nearsightedness (myopia) (e16). The ophthalmologist can detect a cataract by clinical examination of the anterior segments of the eye with slit-lamp biomicroscopy after the pupil has been dilated (*Figure 1*). In this way, the site and extent of opacifications within the lens and their relation to the optical axis of the eye can be determined.

Cataract surgery

Preliminary tests

Before surgery, the patient should undergo testing of visual acuity, examination of the anterior segments of the eye, and fundoscopy for the exclusion of other ocular diseases (e2). The refractive power of the cornea, the depth of the anterior chamber, and the length of the eye are measured, so that the dioptric power of the IOL can be calculated (6, e13, e12).

Anesthesia

According to a poll taken among German cataract surgeons (7), anesthesia for cataract surgery is peri- or retrobulbar, with an injecting needle, in 70% of cases and topical, with drops or gel, in 22% of cases. Similar figures can be found in a number of Cochrane Reviews (e14–e16). Only 8% of procedures are performed under general anesthesia (7). In contrast, data from the American Society of Cataract and Refractive Surgery (ASCRS) and the European Society of Cataract and Refractive Surgeons (ESCRS) show that topical anesthesia is used for most cases in these geographical areas (63% and 56%, respectively) (8). The reasons for using topical anesthesia include rapid visual rehabilitation and the patient's ability to cooperate during surgery when a minimally invasive implantation technique is used (9, e17). On the other hand, topical anesthesia is more difficult for the surgeon and requires a certain degree of compliance from the patient. These are possible explanations for the still relatively high percentage of peri- or retrobulbar injective anesthesia in Germany as compared to other European countries.

Depending on the type of anesthesia chosen, any anticoagulant drugs the patient is taking may have to be discontinued temporarily for surgery. Anticoagulation can usually be continued without any problem if topical anesthesia is used, but the risk of hemorrhage is higher if a peri- or (especially) a retrobulbar injection is performed; thus, in such cases, anticoagulation should be stopped perioperatively. This is true above all for treatment with coumarins, acetylsalicylic acid, or clopidogrel (2).

Surgical technique

Cataract surgery is now most commonly performed in the outpatient setting—in 99% of cases in the USA, and in 84% of cases in the European Union (8, e18). Inpatient treatment is reserved for difficult cases, e.g., when there are accompanying conditions such as infection, glaucoma, or retinal complications.

Antibiotic eye drops are generally given for a few days before surgery, in order to lower the concentration of bacteria on the external surface of the eye and prevent intraocular infection. It has not yet been demonstrated, however, that preoperative antibiotic prophylaxis lowers the rate of postoperative infection, even though a significant reduction of the conjunctival bacterial concentration has been confirmed in a few studies. It is conceivable that preoperative antibiotic prophylaxis actually selects antibiotic-resistant bacterial strains, but this has not been demonstrated yet either (2, e19).

The pupil is pharmacologically dilated for surgery. For reasons of intraoperative safety and postoperative wound stability, self-sealing, sutureless tunnel incisions are mainly used in cataract surgery today, either as scleral or as corneal incisions (8). The superior approach is the classic one for cataract extraction, yet lateral incisions are being used ever more commonly (USA: 65%, EU: 32%) (8). If corneal astigmatism is present, it can be reduced by designing the incision appropriately and placing it on the steep meridian (e20).

The most recent techniques of approach have been designed to keep the incision smaller than 2 mm (*Figure 2*) (11, e21, e22). These techniques, however, require very fine surgical instruments and special, flexible intraocular lenses (IOL) to prevent dehiscence of the wound edges during the operation (11, e17, e22).

The standard method of cataract extraction today is phacoemulsification (10, 12, 13). In this method, the crystalline lens is emulsified and aspirated away through a hollow needle that vibrates at high (ultrasonic) frequency, which is inserted through a centrally placed opening in the anterior capsular sac (capsulorhexis) *(Figure 3)*.

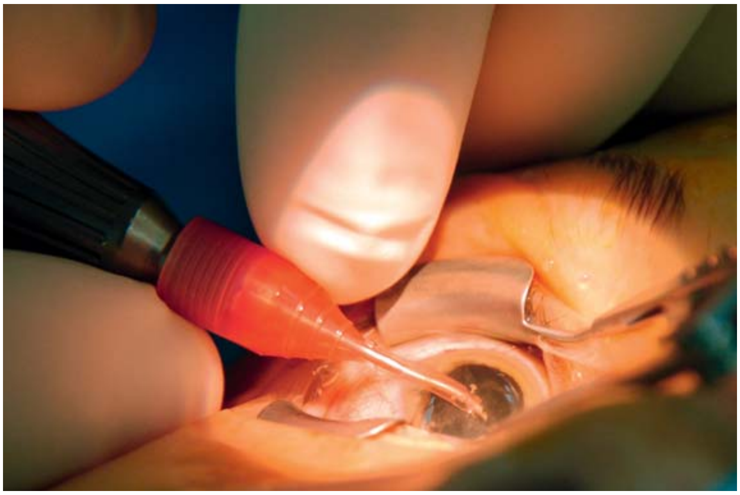

Figure 3: Phacoemulsification of the natural ocular lens

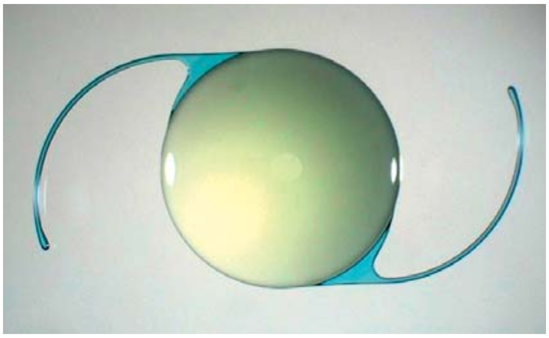

Figure 4: Three-piece spherical blue light-filtering intraocular lens (with standard optics), with C-loop haptics

During the entire operation, the eye is typically protected by the intraocular injection of dispersive and cohesive viscoelastic substances, which additionally give the surgeon the necessary room to operate (13).

Intraocular lenses

Modern, standard IOL are generally spherical *(Figure 4)* and correct the spherical equivalent of the aberrations of the aphakic eye (the overall refractive power of the IOL is approximately 10–30 D). The shape and size of the implant are a function of the site of implantation (capsule or ciliary groove) and the desired lens function (15). Typically, the IOL optics are 6 mm in diameter, and the overall length of the IOL is between 12 to 13 mm. The available types of IOL include rigid polymethylmethacrylate lenses, flexible silicone lenses, and hydrophobic or hydrophilic acrylate lenses. Flexible IOL are now very popular, because they can be implanted through smaller incisions (< 3 mm). In 2007, the percentage of rigid lenses implanted in Germany was under 1%, and the average incision size was less than 2.8 mm (7, 8, e25). In order to lessen the frequency of posterior capsular opacification after cataract surgery (a so-called after-cataract), IOL are currently

Figure 5: Multifocal aspherical intraocular lens after implantation into the capsular bag (shown with retroillumination and with the pupil dilated). One can see the diffractive ring segments, which project two different foci onto the retina, one for near vision and one for distant vision.

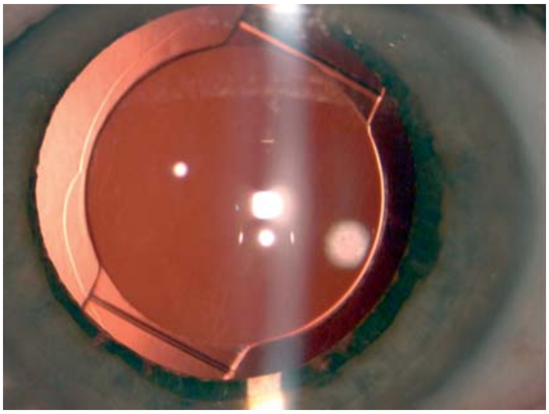

Figure 6: Accommodative aspherical intraocular lens (shown with retroillumination and with the pupil dilated). The photograph shows the special haptics, which are able to bend at a particular position (flexible bending spot) to provide anterior-posterior displacement of the lens as the ciliary muscle contracts and relaxes

being manufactured with a sharp posterior edge. This prevents migration of cells onto the central portion of the posterior capsule and thus prevents a secondary opacification in the visual axis (14, e24).

Intraocular lenses for improving the quality of vision

Modern cataract surgery involves the implantation of intraocular lenses to improve the quality of vision with corrections that go beyond compensation for the defocusing (spherical) error (16).

Aspherical intraocular lenses—Aspherical IOL have an optimized surface curvature in their optical zones, which can correct for higher-order aberration of the spherical aberration. Positive effects of these IOL, including an improved subjective quality of vision and improved contrast sensitivity, have already been demonstrated, particularly when the pupils are large (17, e5, e26, e27).

Toric intraocular lenses—Corneal astigmatism greater than 1.0 D, caused by uneven curvature of the cornea, can be corrected with toric IOL (0.5% of all implantations in 2007, with the trend currently upward) (15). These lenses compensate for corneal astigmatism with a corresponding optical zone. When they are implanted, attention must be paid to precise orientation and rotational stability in order to ensure permanent, optimal correction of astigmatism (17, e6, e28)

Multifocal intraocular lenses—Multifocal IOL (1,2% of all implantations in 2007, with the trend currently upward) (15) give the patient two or more focal points, thereby enabling both near and distant vision without any additional optical correction. Multifocal IOL are classified according to their optical properties as refractive (light-breaking) lenses, diffractive (light-bending) lenses, and lenses combining diffractive and refractive optics (e29, e30) *(Figure 5)*.

Accommodative intraocular lenses—Accommodative IOL have the purpose of restoring accommodation (the variable setting of the eye for near and distant vision) after cataract surgery. The types that are currently marketed and in clinical use are based on the principle of anteroposterior lens displacement; studies have shown them to produce only moderate improvements of near acuity. Accommodative IOL with other mechanisms of action are now under development or in the testing phase (18, 19, e31) *(Figure 6)*.

Blue light-filtering ("yellow") intraocular lenses—Blue filters reduce the transmission of the short-wave component of light, which is thought to induce photo-oxidative injury at the site of sharpest vision on the retina (the macula) and thereby to cause age-related macular degeneration (20). Moreover, short-wave light is more strongly dispersed than long-wave light, because of the effect of chromatic aberration, and this phenomenon can impair contrast vision. Blue light-filtering lenses thus do not impair contrast sensitivity (4) *(Figure 4)*. In the year 2007, 72% of the centers for cataract surgery in Germany implanted an average of 100 blue light-filtering intraocular lenses, and 8% of them implanted more than 500 (15, e32).

Extensive preoperative diagnostic testing and an evaluation of the patient's visual habits and requirements are needed to determine the type of IOL that is most suitable for the individual patient (e33).

Results

The main criterion for the success of cataract surgery, aside for an uncomplicated course of the procedure itself, is the long-term visual result. The most commonly evaluated endpoints are high-contrast visual acuity and the residual refraction deficit at the visual distances for which the implanted lens is intended (6, 21). The expression "quality of vision" has been coined in view of the fact that high-contrast visual acuity, though it can be measured simply and quickly, is not a fully adequate measure of the complex phenomenon of

TABLE 1

Overview of studies and reviews on visual results of different types of intraocular lenses*

Authors, year, reference	Title of publication	IOL optical design	Type of publication	EBM level	HCVA	Distribution of high-contrast acuity values (%)	IOL-specific findings
Powe NR, Schein OD, Gieser SC, Tielsch LM, Luthra R, Javitt J, Steinberg EP (1994) (22)	Synthesis of the literature on visual acuity and complications following cataract extraction with intraocular lens implantation. Cataract Patient Outcome Research Team	Spherical IOL	Meta-analysis	1a	–	≥ 0.5 (95.5%)	–
Kasper T, Bühren J, Kohnen T (2006) (e5)	Visual performance of aspherical and spherical intraocular lenses: intraindividual comparison of visual acuity, contrast sensitivity, and higher-order aberrations	Spherical IOL / Aspherical IOL	Original article	1b	$HCVA_a$ ≈ 0.9 $HCVA_s$ = 0.8	–	No significant difference in HCVA and CS between spherical and aspherical IOL; spherical aberration significantly lower with aspherical IOL
Lin IC, Wang IJ, Lei MS, Lin LLK, Hu FR (2008) (e26)	Improvements in vision-related quality of life with AcrySof IQ SN60WF aspherical intraocular lenses	Spherical IOL / Aspherical IOL	Original article	1b	$HCVA_a$ = 0.8 $HCVA_s$ ≈ 0.8	–	No significant difference in HCVA and CS between spherical and aspherical IOL; spherical aberration significantly lower with aspherical IOL ; no significant difference in vision-related quality of life, as assessed by questionnaire
Bauer NJ, de Vries NE, Webers CA, Hendrikse F, Nuijts RM (2008) (e46)	Astigmatism management in cataract surgery with the AcrySof toric intraocular lens	Toric IOL	Original article	1b	$HCVA_t$ ≈ 0.8 (mild astigmatism) $HCVA_t$ ≈ 1.0 (moderate astigmatism) $HCVA_t$ ≈ 0.8 (marked astigmatism)	≥ 0.5 (≥ 90%) ≥ 0.8 (≥ 80%)	Residual astigmatism ≤ 0.75 D in 75% Residual astigmatism ≤ 1.00 D in 91%
Kohnen T, Allen D, Boureau C, Dublineau P, Hartmann C, Mehdorn E, Rozot P, Tassinari G (2006) (3)	European multicenter study of the AcrySof ReSTOR apodized diffractive intraocular lens	Multifocal IOL	Original article	1b	$HCVA_m$ ≈ 1.0	≥ 0.5 (99.1%) ≥ 0.8 (83.9%)	Uncorrected HCVA near = 0.09 logMAR Acuity > 0.5 near = 100% Acuity > 0.8 near = 97.5% 88% no need for eyeglasses for distant vision 84.6% no need for eyeglasses for near vision
Leyland M, Pringle (19) (2006)	Multifocal versus monofocal intraocular lenses after cataract extraction	Multifocal IOL	Cochrane Review article	1a	–	–	HCVA for distance equivalent to that of monofocal IOL; HCVA for near vision always better with multifocal IOL than with monofocal IOL
Findl O, Leydolt C (18) (2007)	Metaanalysis of accommodating intraocular lenses	Accommodative IOL	Meta-analysis	1a	–	–	Little or no additional of HCVA for near vision with distant correction

* The first item given is the most commonly applied criterion for quality of vision, namely, the (uncorrected) high-contrast visual acuity (logMAR = logarithm of minimum angle of resolution), and its percentage distribution; thereafter, the visual functions with IOL-specific improvement in comparison to other IOL types are listed
HCVA, uncorrected high-contrast visual acuity; IOL, intraocular lens;
CS, contrast sensitivity; HOA, higher-order aberrations;
EBM Level: Oxford Centre for Evidence-Based Medicine Levels of Evidence (May 2001);
s, spherical group; a, aspherical group; t, toric group; m, multifocal group

TABLE 2

Complications of cataract surgery*

Complication	Frequency
Cystoid macular edema (clinical)	1.5%
IOL dislocation	1.1%
Retinal dislocation	0.7%–1.23%
Bullous keratopathy	0.3%
Endophthalmitis	0.13%–0.20%

* modified from an analysis of the literature (Powe, et al. [1994] [22], ESCRS multicenter study [2007] [2], Russel et al. [2006] [25], Erie, et al. [2006] [e47])

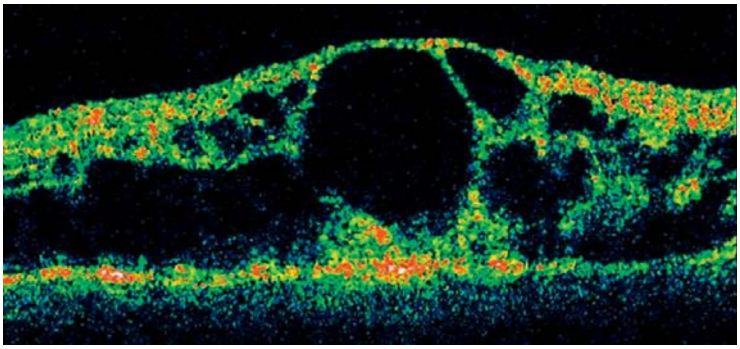

Figure 7: Cystoid macular edema, as revealed by optical coherence tomography

visual perception (e33, e34). Quality of vision is the patient's ability to see well in the context of his or her own individual visual requirements (e35). Various objective and subjective measures are used to determine the quality of vision (6, 22).

A very large number of studies have been published concerning the visual results of cataract surgery, yet the endpoints employed are often not comparable between studies, as they are highly diverse and often subjective, leaving wide room for interpretation. *Table 1* contains data from selected studies—either original articles, systematic reviews, or meta-analyses—that reflect the current state of knowledge concerning the visual results with various types of IOL.

In summary, it can be concluded that high-contrast visual acuity, which is the most important of all visual functions and the one that is most easily measured through the method of successive approximation, enters an acceptable range after the implantation of current types of IOL. As early as 1994, Powe et al. showed, in a literature analysis, that 95.5% of eyes without any other ocular condition, and 89.7% of all eyes treated, reached an uncorrected postoperative visual acuity of 0.5 or better (22). Patients without any other ocular conditions who receive modern, flexible IOL can currently achieve mean visual acuity values of 1.0 or even better (e5, e27). The special optical designs of aspherical, toric, multifocal, and accommodative IOL can further improve results in the particular situations for which they are indicated.

Complications of cataract surgery

Overall, complications are very rare after cataract surgery (<1%).

Intraoperative complications

Complications of injective techniques for local anesthesia, such as retrobulbar hemorrhage, perforation of the globe, allergic reactions to the anesthetic agent, hypotension, and even respiratory paralysis due to accidental injection into the optic nerve and thus into the subarachnoid space, are extremely rare (0.066%) now that anesthetics are increasingly being administered via eye drops and gels (e16, e38, e39). The risk of intraocular hemorrhage is not markedly increased when topical anesthesia is used, even in patients taking anticoagulants (e40). Other potential intraoperative complications depend on the particular operative technique used (e41). These include, for example, damage resulting from the corneoscleral tunnel incision with bulbar hypotension, prolapse of uveal tissue through the wound (e.g., when alpha-1 antagonists are used), corneal injury due to separation of Descemet's membrane or corneal thermoinjury from the phacoemulsification tip, tearing of the capsular sac with subluxation of the IOL, and, occasionally, incarceration or loss of the vitreous body or severe hemorrhage (choroidal effusion, expulsive hemorrhage) (e40).

Postoperative complications

Postoperative pain may be a sign of injury to the corneal epithelium, elevated intraocular pressure, or an intraocular infection (endophthalmitis). Endophthalmitis, one of the more serious postoperative complications of lens surgery (*Table 2*), is currently very rare (0.05 %) (e42) when very strict antiseptic precautions are observed, yet markedly more common if older surgical techniques are used (0.36%) (e43). It was shown very recently in a prospective, randomized multicenter study that an additional intracameral application of antibiotics significantly lowers the probability of endophthalmitis after cataract surgery (2). If endophthalmitis does arise, it is very important for medical and/or surgical treatment to be provided as rapidly as possible. Other rare complications include wound dehiscence with bulbar hypotension, epithelial growth into the wound cleft, allergic scleral reactions to the eye drops, or subluxation of the IOL. Complications affecting the posterior segment of the eye include the occurrence of cystoid macular edema *(Figure 7)*, which usually arises 1 to 3 months postoperatively and usually regresses in a further 6 months, though it produces holes in the retina in 0.4% to 5.4% of cases. The latter may be associated with a so-called rhegmatogenic retinal detachment, i.e., a detachment due to a tear in the retina (e41). The most common complication is postoperative cataract, also called “after-cataract” *(Figure 8)*. While the frequency of postoperative cataract was as high as 50% in 5 years in older publications (23, 24, e44), this has now been brought down to the much lower figure of less than 3% in 3 years by improvements in surgical technique and the use of modern, sharp-edged flexible lenses (e23). If a postoperative cataract should arise, it can usually be eliminated without difficulty by laser capsulotomy (opening the posterior capsule of the lens) with a neodymium-YAG laser. Nonetheless, preservation of a closed posterior capsule helps prevent postoperative complications such as retinal detachment and macular edema, which implies that a further reduction of the after-cataract rate would be desirable.

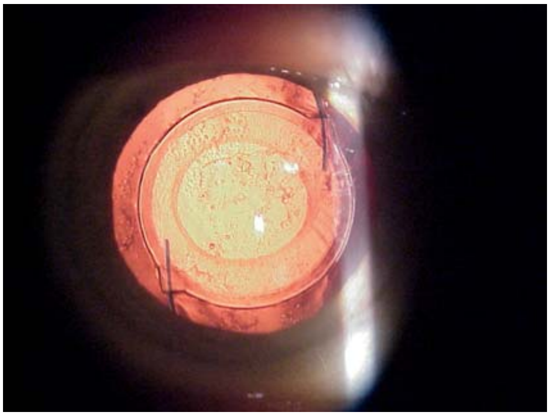

Figure 8: Posterior capsule opacification after implantation of a silicon intraocular lens (shown with retroillumination and with the pupil dilated).

Postoperative medications and follow-up care

Postoperative care generally includes the topical application of a steroidal or non-steroidal anti-inflammatory medication in a tapering dose for two to four weeks, as well as an antibiotic (usually a gyrase inhibitor) for about one week.

The patient should be told to avoid rubbing or pressing on the operated eye, or sleeping on that side of the body, for the first few days after surgery. There should be no direct contact with soap, shampoo, make-up, or the like, nor should the patient swim in a pool or use a sauna. Furthermore, intense physical exercise, such as the lifting of unusually heavy weights, should be avoided for about one week, depending on the particular surgical technique used. The patient can start driving a car again only after the visual acuity has been retested and the ophthalmologist has given approval. It is important to tell the patient to report to a physician immediately in case any new or increasing symptoms develop, so that potentially serious complications can be treated in timely fashion.

The ophthalmologist generally sees the patient in follow-up one day, one week, and one month after surgery, after which a new visual aid can be fitted for near and/or distant vision, if necessary. If steroid eye drops are given for a protracted time after surgery, the intraocular pressure should also be checked after these have been discontinued. Patients often ask how long the implanted artificial lens will last. Intraocular lenses have been implanted since 1949 (23). The only manifestations of implant aging that have been described in the literature are postoperative discoloration and opacification, yet these can be considered rarities that are not expected to occur when modern types of IOL are implanted with up-to-date surgical techniques (24, e45).

Conclusion

When performed by an experienced ophthalmic surgeon, cataract surgery with minimally invasive, small-incision technique is a safe and effective procedure that has a very low complication rate and is followed by rapid wound healing and improvement of vision. Steady improvements in intraocular lens design and the opportunity to implant modern, innovative types of lens now give the patient a high and continually improving postoperative quality of vision, while the likelihood of a serious complication is already low today and is steadily becoming lower.

Conflict of interest statement

The University of Frankfurt has received support for evaluative studies of intraocular lenses from Alcon Pharma GmbH, AMO Germany GmbH, Bausch & Lomb Surgical, Pharmacia Ophthalmics, and Rayner Surgical GmbH.

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KEY MESSAGES

- Cataract surgery can now be performed under gel anesthesia.
- Simple, minimally invasive, small-incision techniques can be used.
- As a result of these methods, rehabilitation after cataract surgery is very rapid.
- Cataract surgery has a very low complication rate.
- The optimized optical design of intraocular lenses improves visual quality and patient satisfaction after cataract surgery.

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REVIEW ARTICLE

Cataract Surgery With Implantation of an Artificial Lens

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